A New Method for Comparing Colour Gamuts among Printing Technologies

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1. Introduction

In colour reproduction, it is generally important for different reasons to know beforehand the colour gamut of reproducible colours (Berns, 2000). Some industries applying industrial colorimetry, such as textiles, plastics, leather, paints, usually keep a data base with their colour gamut, which only occasionally, following commercial criteria and fashion, is reproduced in a sampler to allow the customers to judge the colour generating capabilities of the manufacturer. However, few enterprises study whether their colour gamut reaches the MacAdam limits (see Appendix) or whether it covers more or less homogeneously the Rösch-MacAdam colour solid (Berns, 2000; Kuehni, 2003). Pointer, in 1980, was one of the first scientists to study this problem (Pointer, 1980). In 2002, Pointer retook this subject, asking for the collaboration of all persons interested in the matter, to generate a large database of colour gamuts in current industry (Pointer, 2002). We are particularly interested in this subject, both in those aspects related to the comparison between the colour gamuts of different industries and the MacAdam limits and in those aspects related to how the colour solid is filled, whether homogeneously or leaving certain void regions.

In Colour Imaging there are other reasons why the computation of the colour gamut in colour devices is important, particularly the need for controlled colour management in input, display and printing devices (Green & MacDonald, 2002; MacDonald, Luo, 2002; Wandell, Silverstein, 2003; Kipphan, 2001; Smyth, 2003). Thus, most industries use colour charts to compute the colour profile of colour devices. For many years, for example, the ANSI IT8 charts have served as a reference to calibrate scanners and printing devices. Several works (Cheung, Westland, 2004) have studied the suitability and the efficiency of these colour charts depending on the device to be characterised. It is for this reason that, for instance, two versions of the ColorChecker chart are available for colour cameras: the classic one and the new DC chart. Similarly, many charts (ECI 2002, CIE 2.9 offset, etc) offer now an alternative to the ANSI IT8 7/3 chart for printing devices. The aspects taken into account in the design of these colour charts, such as linearization curves, primary and secondary colours and so on, are those that best characterise the colour device under study. Using these standard colours, the colour gamut of the device can be compared with the MacAdam limits, although few studies have analysed whether the rest of the colours fill homogeneously the Rösch-MacAdam colour solid. For instance, an exhaustive study of the differences arising from the use of different inks and substrates (paper, cardboard, etc.) in the different printing technologies (flexography, gravure, offset, electrophotography, inkjet, etc.) cannot be found in scientific literature.

For all these reasons, and following Pointer, we have developed a simple method to compare the colour gamuts of different printing technologies based on representing the reproduced colours in constant lightness L* and hue h_{ab}* planes. In particular, we focus in this work in the comparison of four printing technologies –electrophotography or laser, gravure, inkjet and offset– using the same class of paper and approximately the same characterization chart.

2. Methods

The printing devices selected for this analysis were three laser printers (HP 6600 Indigo, Xerox Docucolor 12 and HP 4600), one inkjet printer (HP 1220), one offset printing press (Heidelberg GTO 52 with Euro Offset) and one gravure printing press (Hell 324), with the corresponding genuine cartridge units. Trying to get the most homogenous comparative among these printers we used plain paper as substrate (100 g/m^2 and matte or non-coated appearance), except to the gravure printing device, and we decided to print the ECI 2002 CMYK chart for laser, gravure and offset printers. On the other hand, we selected to print the TC9.18 RGB chart for the inkjet printer in order to benefit us from its internal driver model or RGB-to-CMYK conversion.

When it was possible, the spectral reflectance $\rho(\lambda)$ of the patches of each particular colour chart have been measured by a Minolta CM-2600d spectrophotometer (d/8 geometry) using the Minolta SpectraMagic 3.6 control software. The tristimulus values XYZ under illuminant D65 and the CIELAB descriptors L*a*b*C_{ab}*h_{ab}* are computed along with the H V/C Munsell descriptors of the sample. Taking also into account the MacAdam limits under D65 (Perales, et al., 2005), we can select the constant lightness L* and hue h_{ab}* profiles in which the samples of each manufacturer (printing technology) and the MacAdam loci must be plotted. In other circumstances, for instance the gravure data, we use a GretagMacbeth SpectroScanT spectrophotometer (45/0 geometry) to get output data in CIELAB format under illuminant D50 in the corresponding ICC profile.

Once all the patches of each chart/printer are measured in turn, the CIELAB data are grouped in parallel ordering them by increasing lightness L* and hue-angle h_{ab}*. CIELAB data are plotted into constant lightness (luminance factor) planes with a variance of $\Delta Y = \pm 5$ %. On the other hand, the same CIELAB data now ordered by hue are plotted into constant hue-angle planes with a variance Δh^* associated to the hue-angle range of the major hues of the Munsell notation (R, YR, Y, GY, etc). As reference hue-angle for each 2D profile in this case, we selected the corresponding value of each Munsell chip with V = 5 and C = 10 under illuminant C and according to CIE-1931 observer.

3. Results and Discussion

With this methodology some studies can be done:

- calculate and graph the ICC profile data in several constant lightness and hue angle planes.
- compare colour gamuts with different categories of paper (uncoated, coated, recycled, etc) or other substrates in the same printing technology.
- compare among different CMYK and RGB characterization charts and to propose improvements to fill more homogenously the Rösch-MacAdam colour solid.
- search new colorants (pigments and inks) in all printing technologies to reach the borders of the MacAdam limits.

Next, we show some examples of this methodology.

3.1. Comparing among different printing technologies with the same paper

Figures 1 and 2 show a comparison between the colour gamuts of the three printers, using the same class of paper, according to several luminance factor (lightness) ranges. As it can be seen, none of the three printers reach the corresponding MacAdam limits, particularly for the lightest colours (section with Y = 70 %). However, the colour sub-gamut of the lightness mid-range (Y = 20 %) fills well enough the area of the MacAdam loci. Comparing among the three printers, it is obvious that the best one is the laser printer in the four constant lightness sections. The second place in this ranking is for the inkjet printer, although the colour patches of the TC9.18 RGB do not fill homogenously each sub-colour gamut of this printer. Finally, the offset printing machine shows the smallest colour sub-gamuts, especially for the dark colours (Y = 10 %). Perhaps using a coated paper, with a grammage above 100 g/m^2, the colour gamut of this printing device could be significantly increased.

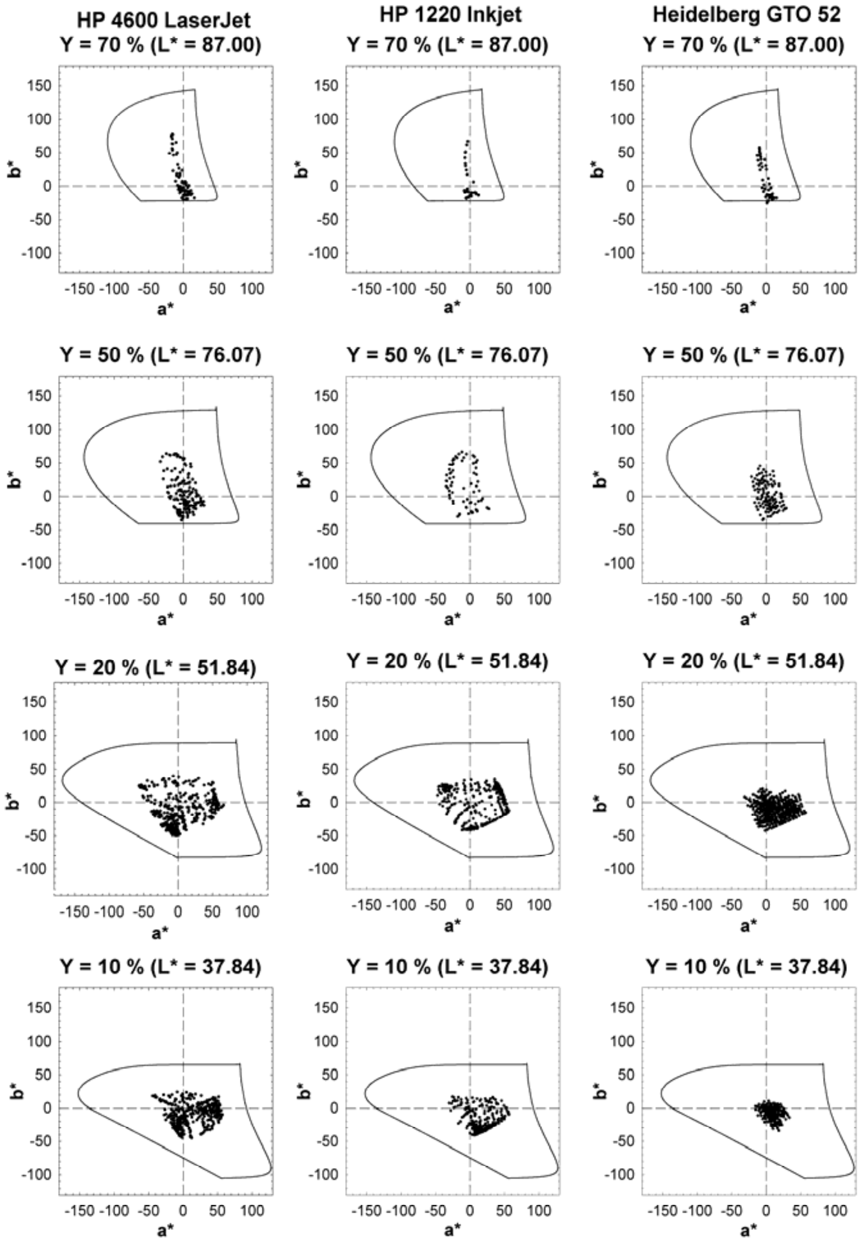

Figure 1: Samples of the ECI CMYK 2002 chart printed in a HP 4600 laserjet color printer (left side) and Heidelberg GTO 52 printing machine (right side) and the TC9.18 RGB chart in a HP 1220C inkjet printer (center) in several constant lightness planes. The outer loci are always the corresponding MacAdam limits.

On the other hand, Figure 2 shows the colour gamuts of the same three printers for the Munsell Hue ranges. As it can be seen, none three printers reaches again the corresponding MacAdam limits. In general, the blue (B) and blue-purple (PB) MacAdam limits are relatively well filled for the three printers. But, in the other extreme case, the green (G) and purple (P) MacAdam limits are the worst filled by the colour sub-gamuts of the printers. Comparing among three printers, it is again obvious that the best one is the laser printer in the ten constant hue angle sections. The second place in this ranking is again for the inkjet printer. However, in this type of analysis, it is common for all the printers to leave empty or un-occupied sub-regions in these hue sections, especially around the achromatic axis, as can be clearly seen in particular with the inkjet printer. Examining each hue section, and taking into account the typical scheme of nuances in constant hue angle profile (Figure 3), it can be seen the following: there are more deep red colours in laser and inkjet printers than in offset printer, there are more strong blue colours in the laser printer but there are more bright blue colours in both inkjet and offset printers, etc.

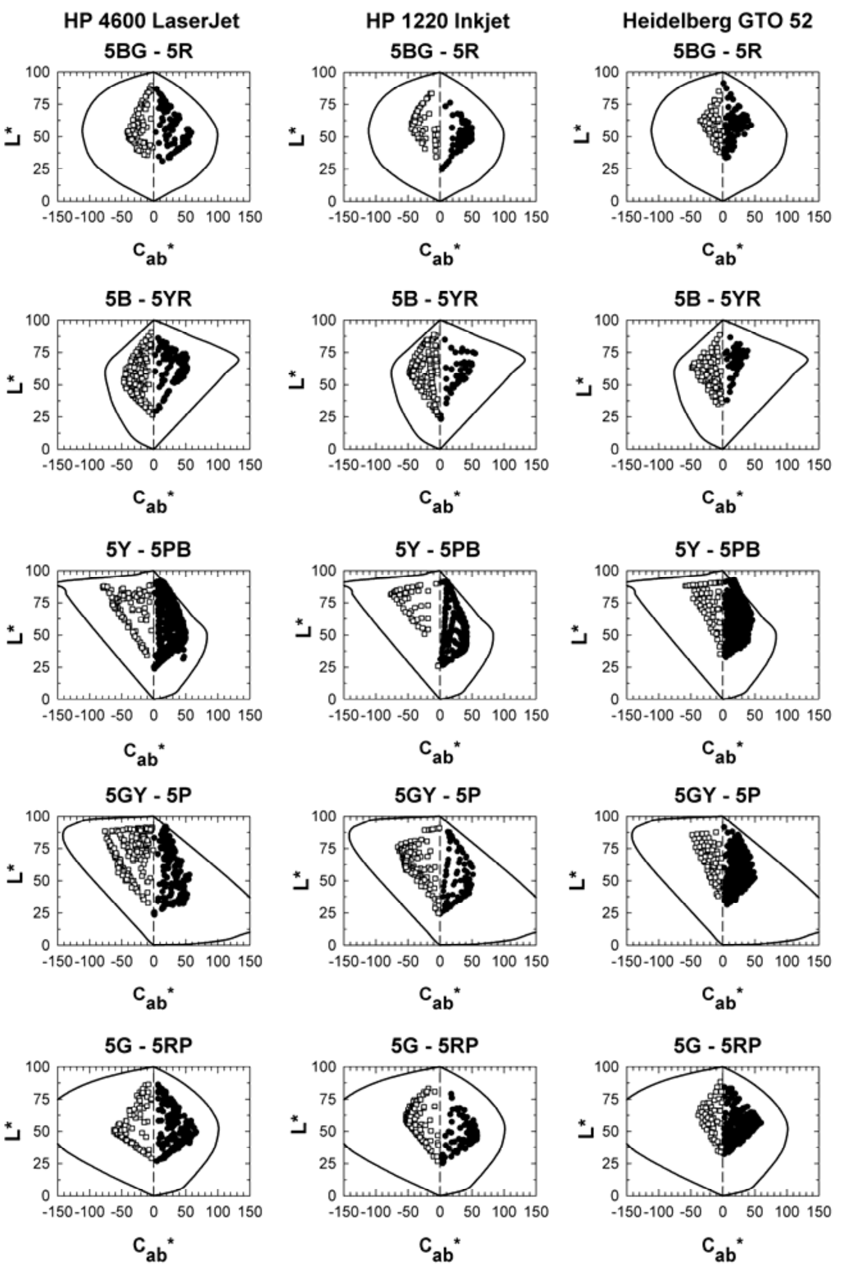

Figure 2: Samples of the ECI CMYK 2002 chart printed in a HP 4600 laserjet color printer (left side) and Heidelberg GTO 52 printing machine (right side) and the TC9.18 RGB chart in a HP 1220C inkjet printer (center) in several constant hue-angle planes. The outer loci are always the corresponding MacAdam limits.

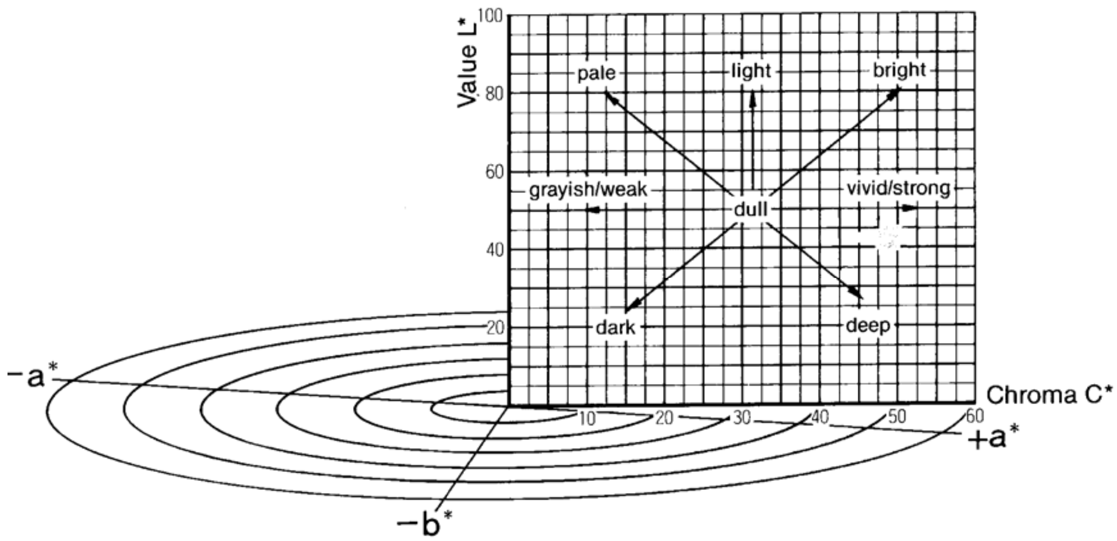

Figure 3: Nuance types in a constant hue-angle section in CIELAB colour space.

In both cases and generalizing, it can be seen that the colour gamut of the laser printer is larger than the rest, above all for dark colours and red hue ranges. The last place of the ranking is occupied by the offset printer. In any case, as it also can be seen, none of the printer colour gamut reaches completely the corresponding MacAdam limits. Moreover, in some specific profiles, both constant lightness and hue angle segments, certain regions inside the colour solid remain empty, particularly around the achromatic axis.

3.2. Comparing the same printing technology with different substrates

Figure 4 shows the colour gamuts of the same web-fed gravure printing press with several substrates or transparent foils for the Munsell Hue ranges. As it can be seen, none colour sub-gamuts with printing technology reaches again the corresponding MacAdam limits. However, comparing with the Figure 2, associated to several printing technologies with paper as substrate, it can be seen clearly that the gravure technology is higher than the other ones (electrofotography, ink-jet and offset). Perhaps, the main reason of this significant difference among these printing technologies is due to the optical nature of the substrate: paper as reflective medium for the first ones, and transparent foil (cellophane, polyethylene, etc) as transmissive medium for the last one. Nevertheless, this analysis among these printing technologies is not almost right because it is necessary to take into account the optical influence of the reflective substrate of the final packaging materials.

In general, all the MacAdam limits are relatively well filled. The worst cases are the green (G) and purple (P) MacAdam limits, but this also was equal in the above printing technologies. Comparing among three transparent foils or substrates, the best one is the foil 1 in the ten constant hue angle sections. Examining each hue section, and taking into account the typical scheme of nuances in constant hue angle profile (Figure 3), it can be seen the following: there are more deep red colours in foil 3 than in other ones, there are more strong blue colours in the laser printer but there are more bright blue colours in foil 1, etc.

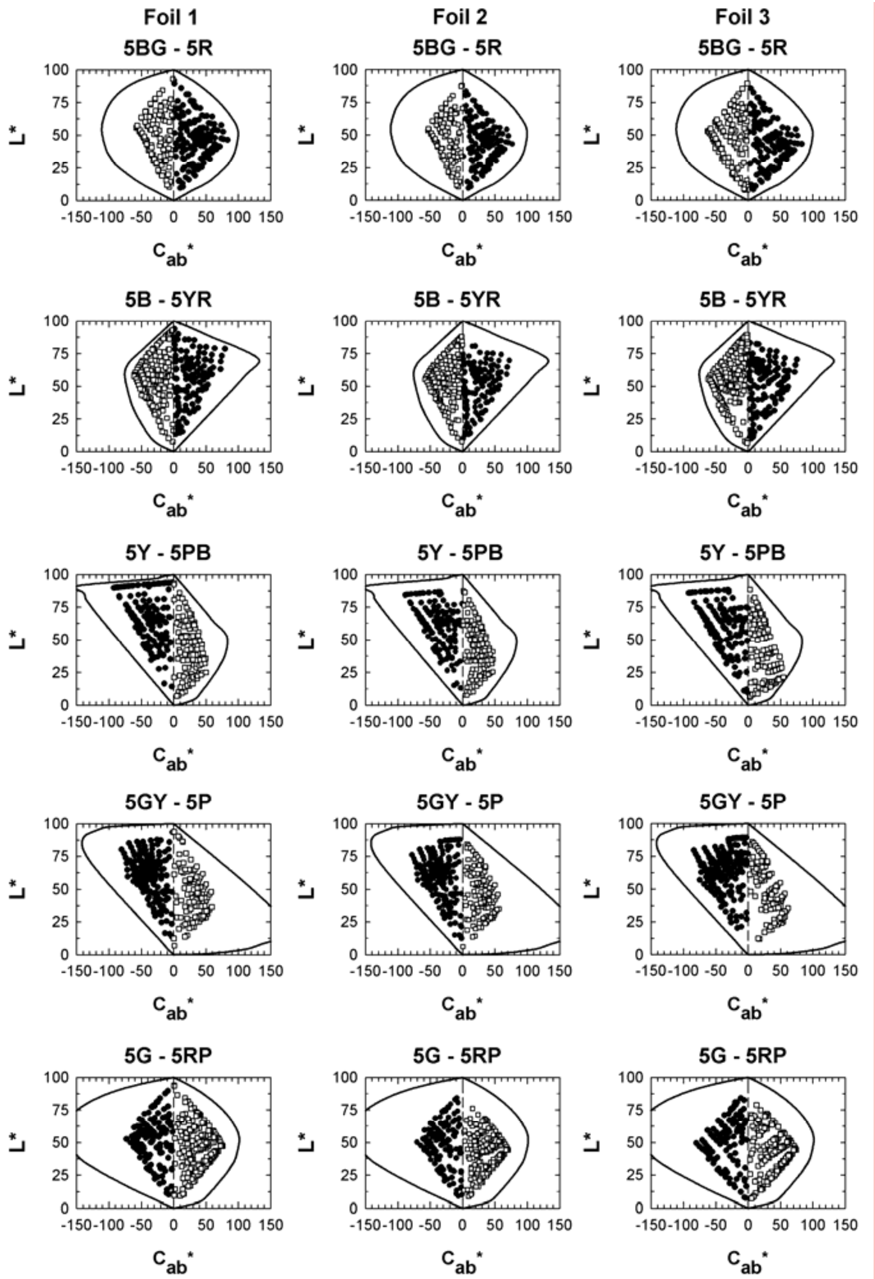

Figure 4: Samples of the ECI CMYK 2002 chart printed in a rotogravure press with several transparent foils in several constant hue-angle planes. The outer loci are always the corresponding MacAdam limits.

4. Conclusions

As an example of the described methodology, which can be applied to any coloration technology (textile, paints, plastics, etc), we compared the colour gamuts of some printing technologies (electrophotography or laser, gravure, inkjet and offset) with the same class of paper and characterization chart (really the ECI 2002 CMYK for the laser, gravure and offset printing devices, but the TC9.18 RGB for the inkjet printer). We show in this comparison that in general the colour gamut of the laser printer is larger than those corresponding to other printers, as appear from both the constant lightness and the constant hue-angle 2D-plots. However, since we always include the corresponding MacAdam limits in the figures, and they are almost never reached for the analysed printers, we think that more research is necessary to obtain new dyes and pigments in printing technologies and paper industry for trying to reach the perceptible limits of the human eye. Therefore, we think that this new methodology, based on the exhaustive analysis of the colorimetric data in CIELAB colour space, could help to off-line quality control in all media print

5. Acknowledgements

This research was supported by the Consellería d'Empresa, Universitat i Ciència of the Generalitat Valenciana (Spain) by means of the grant number IIARC0/2004/59.

6. Literature

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7. Appendix

Human colour perception is essentially tri-variant in nature. Colours are defined by three parameters: lightness, hue and colourfulness (chroma, purity, saturation, etc). This means that colours define a 3D structure named *colour solid*, in whose upper and lower vertex are the absolute or perceptual white and black, respectively. The colours shaping the intermediate frontiers, obviously with the maximum colourfulness, are called *optimal colours* and they were exhaustively studied by MacAdam in 1935. Due to this, the colour solid borders are also known as *MacAdam limits*. Although there are a lot of artistic attempts and preliminary scientific studies to graph realistically the human colour solid, few exhaustive works have arisen since 1935 based on MacAdam's data. We can highlight, as an exception, Pointer's paper from 1980, where different industrial colour gamuts are compared with the MacAdam limits. Since then, these data (Figure A1) have been shown sporadically in colour science textbooks (Berns, 2000; Kipphan, 2001; Kuenhi, 2003), but almost always in chromaticity diagrams, as constant luminance factor loci, with the same illuminants (A, C, D65 or E). However, we have developed recently a new algorithm for calculating the MacAdam limits for any lightness L*, hue angle h_{ab}* and illuminant (D50, F2, F7, F11, etc) or light source (Xe, metal-halide, etc).

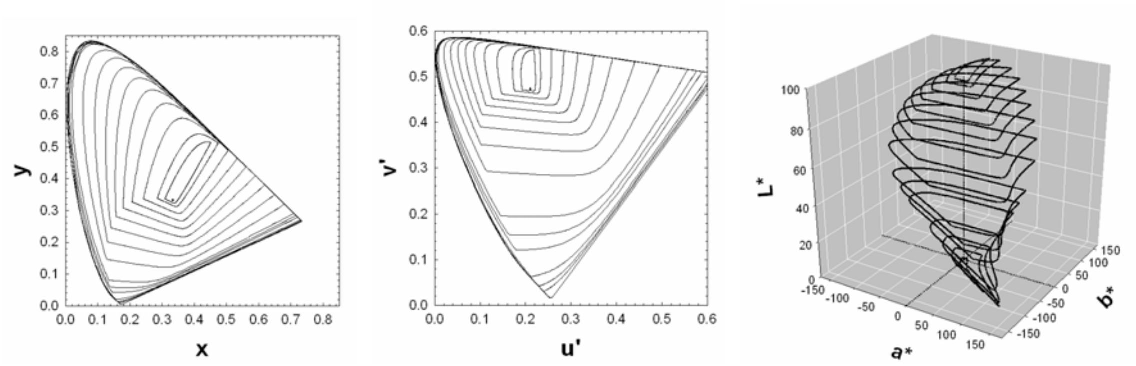

*Figure A1: MacAdam limits under illuminant E according to the CIE-xy (left) and CIE-u'v' (center) chromaticity diagrams and CIE-L*a*b* colour space (right).*

Rösch in 1929, but above all MacAdam (MacAdam, 1935ab), analyzed the theory of optimal colours proving that their spectral reflectance or transmittance can be only zero or one. There are two types of optimal colours (Figure A2): type 1, with "mountain"-like spectral profiles, and, type 2, with "valley"-like spectral profiles. As we know, although these colours are not present in nature, they are very important for Colour Science because they constitute the frontier of the human colour solid. Therefore the Rösch-MacAdam colour solid is the colour space derived from the colour-matching functions (Kuehni, 2003). Due to this, the MacAdam limits are used to analyze the colorimetric quality of colorants (Berns, 2000; Pointer, 1980, 2002) in any industrial application (textiles, paints, printing, etc).

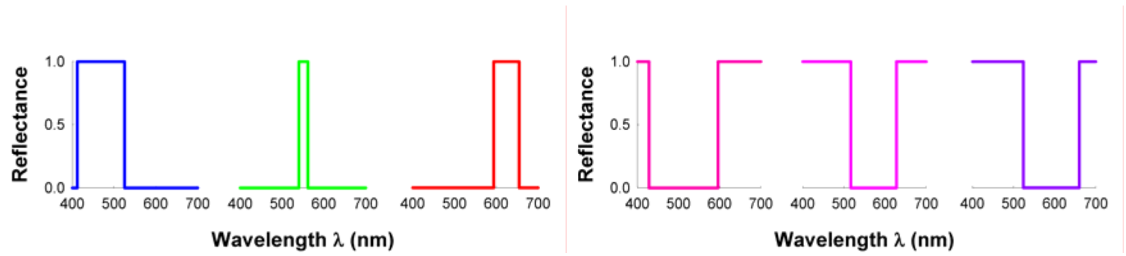

Figure A2: Six examples of optimal colours (left: type 1; right: type 2) with luminance factor Y = 20 % under illuminant E and CIE-1931 observer.